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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Diesel Engines

Part I General Analysis

Four Cycle Air Injection Type

PUBLISHED MONTHLY BY
THE TEXAS COMPANY
PETROLEUM AND ITS PRODUCTS

THE DIESEL ENGINE

IF THE expectations of the advocates and manufacturers of the Diesel type engines are only half realized, the next few years will show an enormous growth in the use of this type of prime mover. In any event, the subject is one of intense present day interest to power producers on land and sea, and so it was, that the Editor, some time ago, planned to have this subject treated completely from a mechanical standpoint.

As this article was being written it became evident that the subject could not be adequately treated in one issue of "Lubrication," and it was decided to divide the article at a logical point, and to run in this issue Part I—"General Analysis—Four Cycle, Air Injection Type" and in October we will discuss Part II—other types.

Therefore we ask you to save this issue, as you may want to refer back to it when you are reading the next.

The Texas Company has been rather fortunately placed as regards the development of the Diesel. As a matter of fact, years ago, when the Diesel was made much of in Europe and America had hardly seen it, we investigated this new unit, studied it and solved its lubricating problem—we developed Texaco Ursa Oil.

Then, as now, Texaco Ursa Oil is the most efficient lubricant on the market for Diesel cylinders.

Texaco Ursa Oil is a clear, clean, pale colored oil with the proper viscosity for the work. It has an exceptionally low pour test and can be relied upon not to clog up the oil pipes when exposed to low temperatures.

It clings to the surfaces of cylinder walls and piston rings—maintains compression, enabling easy starting and delivery of full power.

Texaco Ursa Oil burns cleanly — does not form any troublesome deposits of hard carbon

So, as a general working rule, we can say: use Texaco Ursa Oil to lubricate the cylinders of any type of Diesel engine.

As air compressors used in combination with Diesels, vary so greatly, we shall not make any general recommendation, but if you will tell us, or our engineers in the field, your type of air compressor, a Texaco Air Compressor Oil will be recommended, which will adequately meet the working conditions.

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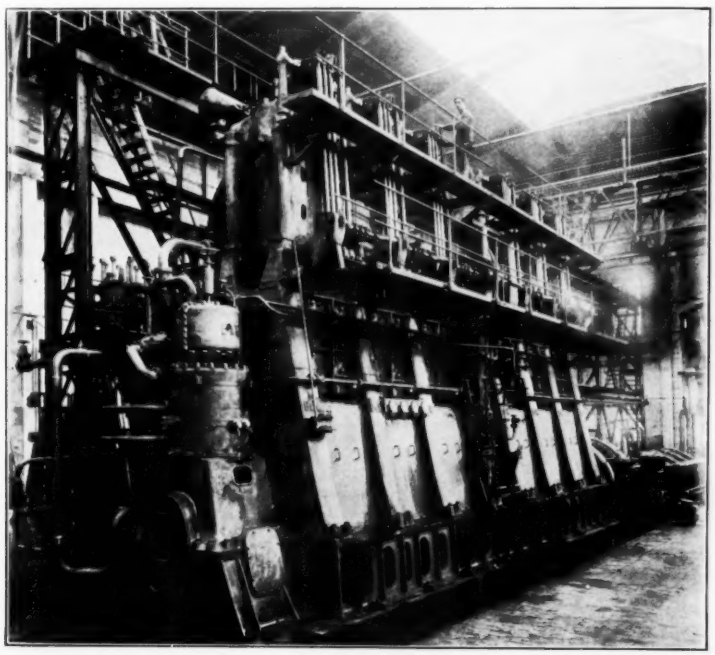


Courtesy of Motor Ship

A typical marine Diesel engine of 2250 I. H. P. Notice the air compressor in the foreground. The man on the top platform indicates the size of the unit.

Diesel Engines

Part I.* General Analysis—Four Cycle Air Injection Type

FOREIGN shipping interests have for several years been intensely interested in the economies of Diesel engine ships. This new entrant into the field of prime movers is so young that many of its principal characteristics are not yet standardized, and are consequently the subject of heated debates between Europe's best engineering talent. Diesel engine construction, particularly in large sizes, is so new that many mechanical details which have nothing to do with the fundamentals of this class of prime mover, have in many designs not been completely perfected and are the real

* Part II, considering other types, will be published in a later issue.

cause for most of the troubles and failures which are cited. It is hardly fair to compare the mechanical perfection of an engine which was little known ten years ago, with the steam engine after its hundred years of evolution. In spite of their short period of development the Diesel engines now built by manufacturers who have had several years' experience with them are surprisingly reliable mechanisms, as is well attested by the large number of ocean-going ships provided with them as the sole means of propulsion.

The tremendously rapid growth of the Diesel engine in marine use during the last decade is shown in Fig. 1, which was compiled from data*

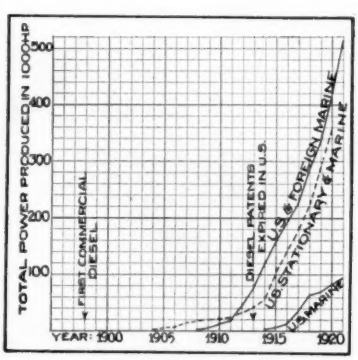


Fig. 1

Yearly production of Diesel Engines, in terms of Horse-power

for vessels having over 100 H. P. and therefore excludes a large number. In the same figure is shown how much of the marine Diesel engine growth has been due to the United States. This country has been severely criticized by many economists for its backwardness in developing Diesel engines for our Merchant Marine, in face of the severe foreign competition which has already tied up much of its shipping. The total of all American built Diesels is also shown in the figure, of which about 25% are employed by the oil companies for their pipe lines. It is difficult to estimate the total production of foreign Diesels, but a statement from Sulzer Freres that they alone have produced over 900,000 H. P. (indicated) of Diesel engines, and an estimate of 500,000 H. P. from Vickers, Ltd., are significant.

During the last few years American firms seem to have realized the importance of this new development, particularly for large units, and now there is quite a list of concerns manufacturing engines over 1,000 H. P., as shown in Fig. 2. Many of these engines, however, are built from foreign designs.

* Motor-Ship Year Book, 1921.

Fig. 2

LARGE DIESEL ENGINES BUILT OR UNDER CONSTRUCTION IN AMERICA

Manufacturer	Cycle	No. of Cylinders	Horse Power	
			Indicated	Shaft
Bethlehem Shipbuilding Co	2	6	3,500	2,500
Busch-Sulzer Bros	2	6	3,400	2,250
Craig Engine & Machine Wks	4	6	2,240	1,850
William Cramp & Sons	4	6	2,250	1,750
Dow Pump & Diesel Eng. Co	4	8	1,885	1,416
Ingersoll Rand Company	4	6	2,600	1,700
McIntosh & Seymour Corp	4	6	2,000	1,525
New London Ship & Eng. Co.	4	8	3,050	2,500
Newport News Shipbuilding Corp.	4	6	2,000	1,450
New York Shipbuilding Corp	4	6	2,000	1,500
Nordberg Manufacturing Co	2	4	2,800	2,000
Pacific Diesel Engine Co.	4	6	1,150	850
Worthington Pump & Mach.Corp.	4	6	2,400	1,760

Superiority of the Diesel

The extraordinary inroads made by the Diesel engine during the last decade into fields so successfully occupied by steam power, suggests that there must be some very vital reason. The reason is not hard to find, for Diesel engines consume about one-third as much fuel as steam engines of corresponding power. Furthermore they make no use of the carburetors and ignition systems characteristic of other types of internal combustion engines. In the ideal and most highly developed Diesel engine any grade of liquid fuel from kerosene to tar oil can be used since it is injected directly into a cylinder when the upward stroke of the piston has compressed pure air to such a pressure and temperature that the fuel burns as it is sprayed in. Many types of Diesels, however, are not sufficiently developed to burn the heaviest

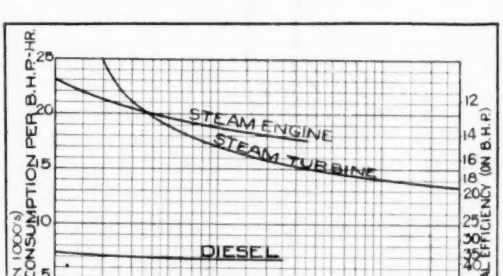


Fig. 3

Variation of probable efficiencies of Steam and Diesel Engines with size of unit (compiled from data in Bulletin No. 156 of Bureau of Mines).

grades of oil. It is a characteristic difference between steam and Diesel units that the efficiency of the former, particularly steam turbines, increases materially with the size of the unit, while with Diesels the size has little effect on efficiency. Thus there is a tendency in stationary service to segregate steam power in large units which tendency does not exist with Diesel engines. Even a 45,000 horse-power steam turbine unit consumes 85% more fuel per horse-power developed than a Diesel as small as 300 H. P.

In marine service the saving of two-thirds of the fuel which would be used by steam outfits results not only in a decreased operating expense, but also in an increased earning power because of the additional tonnage available for paying cargo. This is indicated clearly in Fig. 4

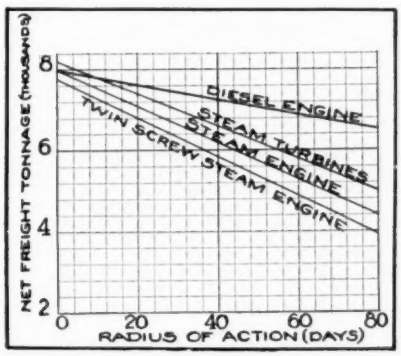


Fig. 4

Effect of various types of power on the net paying cargo possible for a 12,500 gross tonnage freighter, when bunkered for various lengths of cruises.

which shows the net (paying) tonnage available for a typical 12,500-ton displacement vessel on cruises of various lengths, with several types of propelling machinery. There is so noticeable a difference in cargo capacity between a steam and Diesel powered vessel when bunkered for fairly long cruises that when costs are compared it is really necessary to compare vessels of different gross tonnage, in order to have the same cargo carrying capacity. That is, a larger vessel with greater power for steam should be used for comparison with a Diesel ship.

Figures of running expenses and earning capacity are of vital importance in questions of foreign trade, and often spell the difference between profit and loss in days of competition. It is for this reason that foreign shipping is giving such a stimulus to the production of Diesel ships.

Besides such advantages as these which are directly associated with costs, the Diesel engine is at an advantage because it can be started from cold in a minute's time. Not only does this eliminate the stand-by losses of steam boilers when the fires are banked, but emergency starts are possible at a moment's notice.

Disadvantages of Diesel Engines

The one serious drawback to the present day Diesel is its high first cost. Generally speaking a Diesel engine costs almost twice as much per horse-power as the corresponding steam engine with its boilers and auxiliaries. This means that the relative cost of power between a Diesel and a corresponding steam engine depends on the number of hours of service secured per year, for if power is required only occasionally the interest and depreciation which run on regardless of operating or idle time, will more than outweigh any advantages resulting from lower fuel consumption. Thus, in order to show the greatest advantages of the Diesel engine it should be run in as continuous service as possible.

Fears for lack of reliability can be dismissed, for when trouble has occurred in the past it has been due to imperfections in mechanical design which had nothing to do with the fundamental features of Diesel engines. In many engines the imperfections were entirely eliminated as the designers became more experienced. This is shown by the fact that many Diesel engines are in as regular use today as any steam engine. The whole class of engines should not be made to take the blame for the faults of preliminary efforts of inexperienced designers.

Fuel Consumption

Fuel economy can be considered from two standpoints:

1. Consumption
2. Cost

In discussing the fuel consumption of Diesel engines comparison should be made with other oil-burning installations, as a consideration of coal involves many other factors, as transportation, storage, bunker space, etc., which only complicate the discussion. Diesel engine advocates show that this form of internal combustion engine consumes about one-third of

the fuel which would be required for steam producing outfits of same output using oil as a fuel. If all the oil-burning steamships of the U. S. were equipped with Diesels it is claimed that there would be a saving of 40,000,000 barrels of fuel oil per year. This sooner or later must be considered even though the visible supply of fuel oil seems sufficient for many years. While fuel consumption may not be the whole story, nevertheless the claims of Diesel engine manufacturers have sufficient backing as to merit very serious consideration by fuel economists.

In Germany the desire to save fuel oil and to make the greatest use of the thermal value of coal has brought the suggestion from eminent authorities that all coal should have its tar oil extracted for use in Diesel engines, and the resulting coke used in place of coal. Tar oil, as well as by-product vegetable oils such as Soya-Bean Oil, Palm Oil, etc., are used as Diesel engine fuel in Europe and in out of the way places of the world, but it is fortunate that this is not necessary in America because such oils have higher ignition temperatures and are consequently much more difficult to use.

Practically all American fuel oils are derived from crude petroleum by the removal of some of the lighter products—"topped." Fuel oils are usually graded either according to the specific gravity or the Baume scale, though there is a rational tendency to grade according to viscosity. Though viscosity roughly increases with specific gravity, oils of same gravities from different localities may have different viscosities. This makes it impossible to determine either viscosity or volatility by gravity unless the source is known. All grades of fuel oil from petroleum have ignition temperatures low enough to give no trouble when used as boiler or Diesel fuel. Fuels of high viscosity, however, are so difficult to handle because of their sluggish flow to and through piping and the difficulty of atomizing them that they are not in as great demand as those grades of lower viscosity, and are consequently available at lower cost. As is well known, the viscosity of all oils falls as they are heated, which makes it possible to use even the most viscous oils if they are sufficiently heated, but if through accident or carelessness the pipes conveying them, particularly to the pumps, are allowed to cool, it is a disagreeable task to "thaw" them out again.

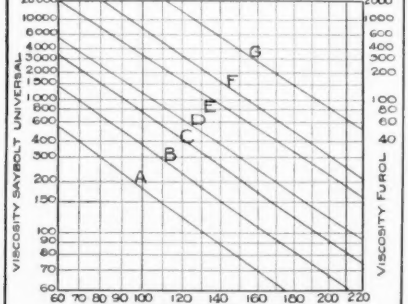


Fig. 5

Effect of temperature on the viscosity of typical American Fuel Oils, ranging from about 25° to 14° Baume.

It is considered good practice with the less viscous, and exceedingly desirable with the more viscous grades which require heating, to stop Diesel engines on kerosene or similar oil so that starting from cold will be easy. As soon as the engine is warm after starting it may be switched over to fuel oil again. Two other decided advantages result from this practice: 1. The Kerosene washes out the fuel system and spray nozzles, thus keeping them from gumming. 2. Corrosion is lessened. Fuel oils sometimes contain sufficient sulphur to form sulphuric acid in the exhaust due to the water present. As long as the gases are hot enough to keep water vapor (a product of combustion) from condensing, no harm will result, but when an engine is stopped and allowed to cool, water will collect on the cool metal and the acid formed will cause serious pitting. This is, of course, avoided by stopping and starting with an oil like kerosene. This procedure makes possible the use of a fuel oil fairly high in sulphur and low in cost.

Cost of Fuels

All grades of fuel from crude oil have about the same heat value or available energy per pound, the heaviest fuel oil having only about 12% less than aviation gasoline, as shown in Fig. 6. On the other hand, the greater density of the heavier oils results in a materially higher heat value when based on volume, and this is the customary method of selling. The more volatile (and less viscous) fuels, however, are easier to use, and in the case of many engines now built, are the only ones that can be used.

The result is that in commercial practice there is found a greater demand and consequently a higher price for these fuels. Most types of internal combustion engines, though not all, can be adapted to burn a light gasoline; kerosene engines of the carburetor type are still in the development stage; the so-called semi- and

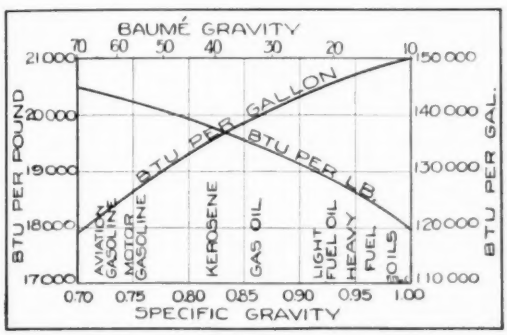


Fig. 6

Relation between the heat value per pound and per gallon of representative American Petroleum Fuels with their specific gravity.

super-Diesel engines can make use of still heavier fuels, but no internal combustion engine other than the highly developed Diesel can at present make use of the heavier fuels which represent a large proportion of the bulk of the output from crude oil. The result of this balance between supply and demand is a market price for fuel oil about one-tenth of that for gasoline in bulk.

This summary of economic conditions surrounding the recent growth of Diesel engines has been given because of the strong indication of a further large expansion of this type of prime mover in the near future. The signs of the times indicate that a careful study of Diesel engines is warranted by those who care to keep abreast or just a little ahead of current developments. For this reason an elementary study of the fundamentals of Diesel operation will be given, together with some of the principal features of Diesel engine types.

The Four-Cycle Type

The separate steps of the four-cycle type are shown diagrammatically in Fig. 7, from which it is seen that four complete strokes of the piston from one end of the cylinder to the other are necessary in the operation of a complete working cycle. To be more exact it should be called the four-stroke cycle, but common usage has abbreviated it to the term "four-cycle". This operating cycle will be recognized as identical with that used in all automobile engines with the single exception of the method of getting fuel to the cylinder. In automobile engines and all other carburetor engines, known as "Otto cycle" engines, the fuel is mixed (and supposedly vaporized) with the air before it is drawn into the cylinder on the admission stroke. In the Diesel engine no fuel is mixed with the air drawn into the cylinder until the beginning of the power stroke, when it is sprayed as a very fine mist into the air and burns as admitted because of the high temperature of the air due to its compression. In

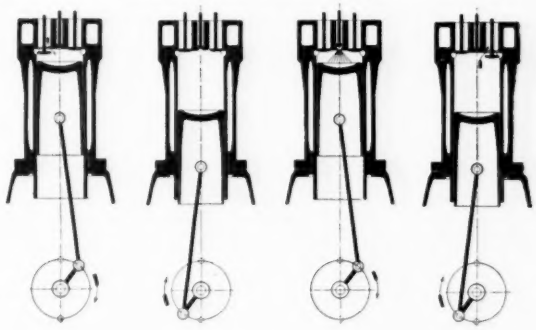


Fig. 7

(a) First stroke (suction), piston travels down; admission valve open; cylinder is being filled with *pure* air.
(b) Second stroke (compression), piston travels up; all valves closed; air in cylinder is being compressed to about 500 pounds per square inch, which heats it to about 1000° F.
(c) Third stroke (power), piston travels down; fuel valve opens at top dead-center, and sprays fuel into the compressed air which is hot enough to burn it as fast as admitted. There is no explosion, and no rise in pressure. Fuel valve closes after about 1/10 of stroke; gases expand.
(d) Fourth stroke (exhaust), piston travels up; burnt gases are expelled from cylinder thru the open exhaust valve.

the Diesel engine then, compression must be great enough to cause ignition of the liquid fuel when it is injected, which means a pressure of at least 450 to 500 lbs. per square inch. Conversely, in the automobile engine (Otto engine) compression must not be great enough to ignite the fuel mixed with the air, and consequently is limited, as far as pre-ignition is concerned, to 100-150 lbs. per square inch. This is a very important difference, because the thermal efficiency, and the power developed from a given quantity of fuel increase for both types of engine as the compression* is raised. For a given compression the Otto engine is theoretically more efficient than the Diesel, and the superiority associated with the Diesel is due to the fact that it uses a much higher compression. The higher efficiency of the Otto for a given

* This means ratio of pressure after compression to pressure before compression, and not the actual compression pressure.

compression is due to the fact that combustion occurs so much more rapidly than with the Diesel, causing a great rise in pressure, while with the latter type there is practically no rise in pressure. The result is that in spite of the high compression of Diesel engines, the maximum pressure during the cycle is usually but little higher than is frequently obtained in high compression Otto types, as airplane and racing engines. A comparison is made of indicator cards from these two engine types in Fig. 8.

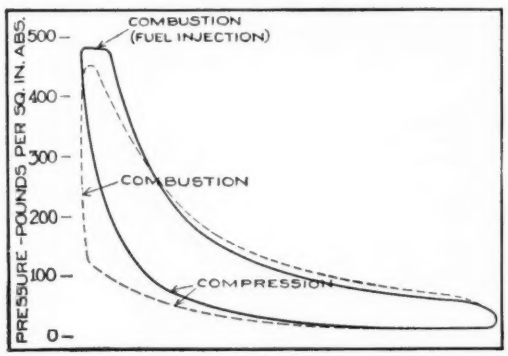


Fig. 8

A characteristic indicator card of a Diesel Engine (solid line) superimposed on a similar card for a Liberty Airplane Engine, Otto cycle (dotted line) showing that the gas pressures of the former are not much greater than those of the latter.

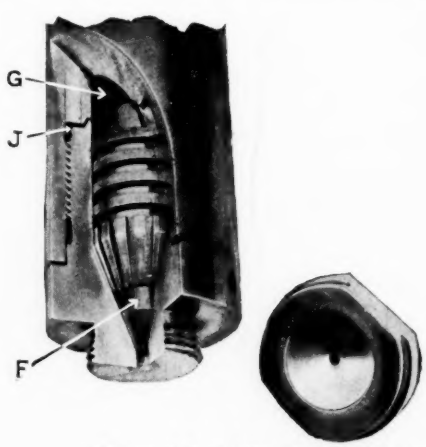
Another point of contrast between the Diesel and Otto types of engines is the means by which regulation is accomplished for light loads. As the Otto can operate only with such quantity of fuel mixed with air as will make an explosive mixture, and since air and fuel mixtures explode only between very narrow percentage limits, it is not possible to regulate its power output by varying the quantity of fuel used without varying the quantity of air also. Thus the compression and also the thermal efficiency is lowered at fractional loads. This is not the case with the Diesel since the quantity of fuel used can be reduced as far as desired without affecting the air or the compression, with the result that at light loads the Diesel engine does not suffer as great a proportionate increase of fuel consumption as the Otto.

Further comparison is not necessary here, except to recall that the ignition systems which are so vitally necessary for Otto engines are entirely absent from the Diesel engine.

Fuel Injection

Fuel injection is accomplished by atomizing with compressed air much in the manner of medicinal atomizers, and until recently this was the only successful method. A very fine "pulverization" of the fuel is absolutely essential for quick smokeless combustion, and is the crux of successful Diesel operation. The injection air pressure must be several hundred pounds above that in the cylinder at the moment of injection, and consequently ranges from 700 to 1,000 pounds per square inch. The actual pressure should be varied if the speed or load vary materially, and while adjustment is often made by hand, several very successful means have been used by which this is done automatically. If the pressure is too low the exhaust is smoky, while if too high the engine "knocks" as a result of a rise in the cylinder pressure due to the explosive effect of injecting the fuel too rapidly. Smoking sometimes results from too low a compression pressure, due to leaky cylinder valves or bad piston rings.

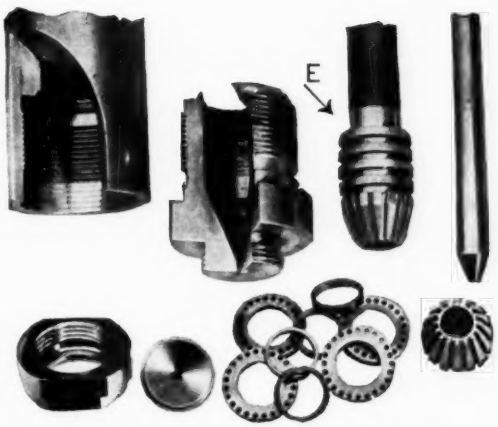
In Fig. 9 is shown a sectional assembly of the lower part of a typical fuel valve, the parts from which it is assembled being shown in Fig. 10. The needle F is ground to its seat and opens the valve by being lifted upward. The space G is continually under the pressure of the injection air. At proper intervals, a measured quantity of fuel oil is forced through the space J against the air pressure, and when the valve needle is lifted at the moment of injection, air in space G mixed with the oil present is forced through the fine holes in the perforated rings and after traversing these irregular paths the mixture is so complete and divided that when it enters the cylinder the expansion of the



Courtesy of Busch-Sulzer Bros. Diesel Engine Co.

Fig. 9

A section of the lower part of a widely used type of Diesel spray valve.



Courtesy of Busch-Sulzer Bros. Diesel Engine Co.

Fig. 10

Disassembled parts of the spray valve shown in Fig. 9

air sprays the fuel as desired. At the right of Fig. 11 is shown another successful atomizer which would take the place of the group of rings, spacers and cone shown at E in Fig. 10. This, however, lacks the flexibility given for various fuels by the former atomizer which is accomplished by varying the number of rings.

The action of this atomizer is a little different than that of the former, since a single charge of oil never rises high enough around the atomizer to pass by gravity through the lower diagonal holes shown in the section. When the needle valve is raised, the air rushing through the upper set of diagonal holes and through the tapering passage surrounding the needle stem develops an injector action which draws the oil into the air stream through the lower holes. There is in consequence little danger of a slug of unatomized oil being driven ahead of the air when the valve is first opened. The high air pressure in the valve necessitates packing the needle valve as is shown in the assembly at the left of Fig. 11. This packing must be kept tight, but if too tight will prevent the valve from closing and cause much trouble.

The vital importance of the fuel valves, together with their number of minute holes and passages emphasize the desirability of taking precautions to see that there is no solid sediment in the fuel oil, and of using kerosene just before stopping so as to wash out any tarry substances which might gum them. It must be remembered that the expansion of the injection air with the fuel has a cooling effect, which requires a higher cylinder compression

Courtesy of McIntosh & Seymour Corporation

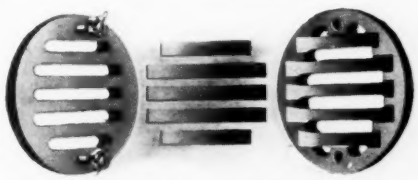
Fig. 11

Cross-section of a Diesel spray valve (Hesselman system). At the right is shown the atomizer disassembled.

than would otherwise be needed in order that the resulting temperature will be sufficiently high for ignition.

Air Compressors

The compressor which supplies the injection air is one of the most important and vital auxiliaries of a Diesel engine, and one which requires particular attention in order to be sure that it



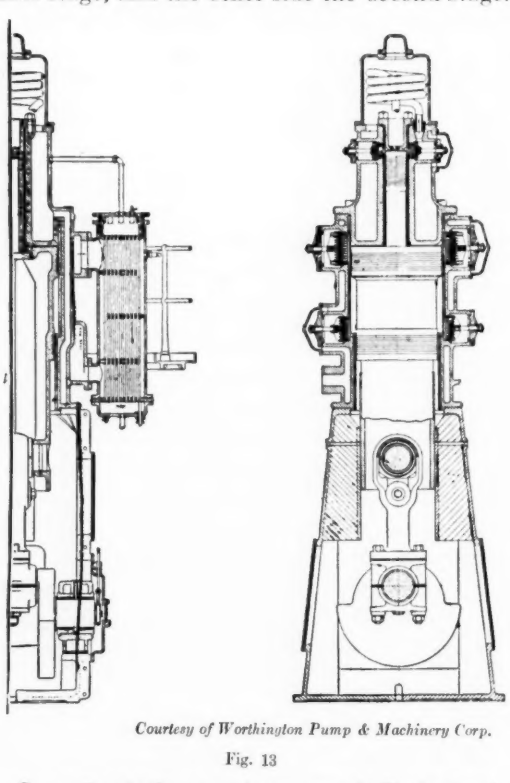
Courtesy of Worthington Pump & Machinery Corp.

Fig. 12

Disassembled parts of one type of very light automatic valve used on the Diesel Air Compressor of Fig. 13. The flat strips act as check valves.

functions properly. The amount of air handled by the compressor is about 5% of the total capacity of the cylinders, and in compressing it to approximately 1,000 pounds per square inch almost 10% of the power developed by the engine is expended. Compressing and handling air at such very high pressures is a formidable matter. If even one of the small steel tubes carrying the compressed air to an injection valve fails, the amount of energy liberated will cause an explosive effect that may badly injure anyone close at hand. Copper tubing is recommended by some engineers who state that in case of failure, on account of its ductility it will split and not fly to pieces as does steel.

In standard practice the compressor is direct-driven at the end of the engine, and divides the work of compression between three stages, with the water-cooled "receivers" or "intercoolers" between the stages. The cylinders which are water-cooled, are usually provided with some form of very light automatic valve. A typical compressor is shown in Fig. 13, the upper side of the center piston handling the low pressure or first stage, and the other side the second stage.



Courtesy of Worthington Pump & Machinery Corp.

Fig. 13

Cross-section of a three stage air compressor of a Diesel engine, the intermediate stage being at the bottom. The half section at the left shows an "intercooler" with its baffles.

The inter-coolers reduce the temperature rise due to compression, and hence the volume of air before entering successive stages, which, as a result, reduces the power required for the compression. There is also a considerable saving in regard to lubricating oil consumption because of the much lower air temperature. When the air is cooled in the receivers appreciable quantities of water condense, varying with the humidity of the atmosphere. Unless it is possible to remove all this water from the air before it enters the next stage it will have a pronounced tendency to wash the oil from the cylinder walls and, of course, cause trouble. There is always some means provided for draining all condensate from the inter-coolers, and careful operators do so more than once an hour in marine work. The presence of water in the compressor makes it imperative that no sulphurous exhaust gases be allowed to mingle with the air drawn into the compressor, for the sulphuric acid formed is very destructive and will not only ruin the lubrication but pit the metal.

Compressor Lubrication

One of the secrets of successful compressor operation is its lubrication, and it cannot be over-emphasized that the least possible quantity of oil must be used. Any excess will carbonize because of the temperatures to which it is exposed. This carbonaceous matter is sticky in the early stage of its formation, which gives it a tendency to adhere to the piston rings, valves, receivers, and may be carried even to the fuel valve parts. In its later stages the carbon forms a hard solid that interferes with the operation of the compressor. Unfortunately there is no oil which will not deposit some carbon, but there is a surprising difference in the quantity of carbon deposited by different oils. Consequently not only must oil be selected with care, but particular attention must be paid to prevent the use of more oil than is necessary. This is one of the principal reasons for arranging the stages of most air compressors with the intermediate stage at the bottom, as shown in Fig. 13. In this construction there is always a pressure opposing the tendency of oil to work up into the air space from the lowest cylinder wall where it is thrown by the crank-pin. In fact, at least one manufacturer has found it necessary to cut down the quantity of crank-case oil so much in order to keep it from getting

by the pistons, that the wrist-pin has to be lubricated by a telescopic pipe arrangement somewhat similar to that used when the pistons are oil cooled.

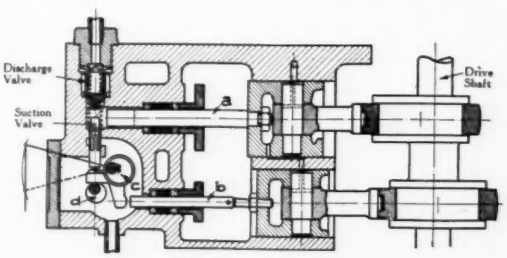
Each cylinder is supplied with a mechanical lubricator which feeds small, measured quantities of new oil to these parts. It has been found that only a drop or two a minute to the first two stages is sufficient, the third stage being abundantly supplied by oil carried up from the second. The safe course to follow in regulating the quantity of oil used is to remove the valves from time to time and examine the cylinder walls. They must have enough oil to feel oily, but no more.

A knowledge of the heat due to compression has caused an unfortunate confusion in the minds of some operators as to the interpretation of the flash points of the lubricating oils for air compressors. Flash point readings are of value only in indicating the relative volatility of different oils, and are not definite temperatures at which they "boil" or go completely into vapor corresponding to the boiling point of water. With oils of higher volatility, a slightly greater quantity will be required to keep a film on the cylinder walls, and consequently a greater quantity will be carried into the receiver in the form of vapor. This can do no harm whatever because an oil with a flash of over 300° F. will never be carried into the air in such quantities as to even approach a combustible mixture. A combustible mixture would necessitate the presence of almost one gallon of oil to be vaporized in each thousand cubic feet of free air or about each hundred feet of compressed air. On the other hand, the oils which leave unusually low carbon deposits have lower flash points than many which leave large deposits. Hence the balance must be drawn between getting a moderate amount of vapor and very little carbon in the air, or appreciable carbon and only a little vapor. Several cases of air compression explosions which have been investigated carefully suggested that the cause was excessive carbon deposits in the piping, which had greatly restricted the area of the passages. The real cause of these explosions is still to be explained satisfactorily, but it is to be noticed that practically all occurred in piping remote from the compressor, and hence at places not subjected to the highest temperatures. Use of oil made from so-called "cylinder stocks" in a compressor in spite of its high flash point is thus certainly questionable to say the least, because of the probability of very high carbon residues.

It is very desirable to clean out the air compressor system at intervals, and wash out the carbon deposits before they grow to large proportions. Kerosene or any similar light oil must under no circumstances be used for this purpose, because of the danger of explosive mixtures due to their great volatility. Some operators look with favor on the use of soap suds for cleaning, the solution of soft soap and water being fed into the air intake or through the lubricator about ten times as fast as the usual oil supply. The quantity used must be judged by the amount of carbon found on the valves when they are inspected. After such an application all receivers must be blown down to remove all the soapy water, and oil used again for a time before shutting down, in order to prevent rusting.

Fuel Pumps

The smoothness of operation of an engine is dependent on each spray valve being supplied with exactly the same quantity of fuel, and the sensitiveness of the control of the engine speed or power output is dependent on the ease with which the quantity of fuel delivered to the cylinders can be regulated. These pumps must accurately measure exceedingly small varying quantities of fuel and deliver them at just the right time, against an injection air pressure sometimes equal to 1,000 pounds per square inch. It is customary for a single pump with automatic valves to be used for each spray valve. With most engines control of the delivery is made by holding the inlet valve open during part of the delivery stroke. Fig. 14



Courtesy of Busch-Sulzer Bros. Diesel Engine Co.

Fig. 14

Section of a frequently used type of Diesel fuel pump, which regulates the quantity of oil delivered on each stroke by the time the inlet valve is held open.

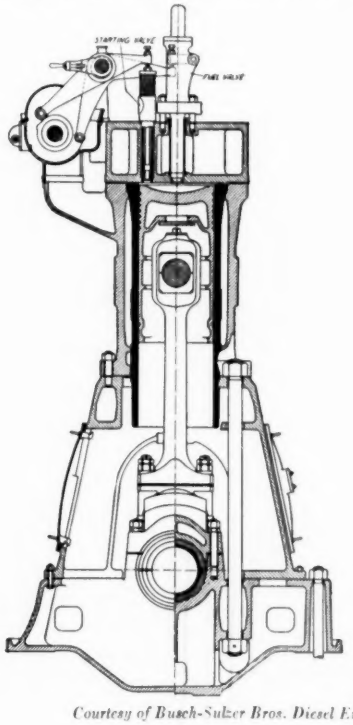
shows how this is accomplished, "a" being the pump plunger, and "b" the "regulating-rod," both being driven by eccentrics. The eccentric driving the regulating-rod is so timed that it may or may not lift the suction valve, depending on the position of the bell-crank fulcrum "c". Complete control of the delivery of fuel is maintained by varying this fulcrum. The engine may be stopped by rotating the eccentric "d" until the suction valve is held off its seat permanently, thus stopping the delivery of fuel. Further movement of eccentric "d" would raise the suction valve so far that it would also lift the discharge valve. This is done before starting an engine when it is necessary to remove all air from the fuel lines. At each fuel injection valve there is a hand-operated overflow valve, which is opened when the discharge valve of the fuel pump is lifted as just mentioned. Then, if the fuel supply is above the fuel valve, fuel will flow by gravity through the fuel pump and lines up to the overflow valve. As soon as a steady flow of fuel is secured at this point the overflow valve should be closed. There is, of course, a check valve between the overflow valve and the fuel valve to prevent the escape of injection air when the overflow is opened. In some instances, especially marine installations, it is not possible to provide a gravity feed which will cause the flow just described, but the flow is caused by hand operated plungers on the fuel pump, or the pump itself is rotated.

Another method of controlling the delivery of fuel from the pumps is by altering the strokes of their plungers by varying the throw of eccentrics driving them. Many detailed changes of these two principal types of pump are made use of by different designers. Marine engines are usually provided with overspeed governors to prevent them from "racing" when the propeller is partly out of water in a heavy sea.

Typical Cylinder Arrangements

The typical Diesel engine of modern design, particularly in marine service, is the vertical, single-acting type, with enclosed crankcase. All valves, inlet, exhaust, fuel and starting-air are almost invariably located in the cylinder head because the high compression requires a clearance space too small for valves in other locations, even if any advantage would result therefrom. Marine engines have at least four cylinders if of the two-cycle type or six cylinders if of the four-cycle type, in order to make starting easy and minimize torsional as well as vertical vibration. Some submarine engines have eight, ten and even twelve cylinders in line. There are, of course, all sorts of other cylinder arrangements, but they are encountered only occasionally.

There is much variation in practice as to the method of taking the side thrust of the connecting rod, some manufacturers using a cross-head while others take it directly on a trunk piston as is shown in Fig. 15, and as is done on all automobile engines. The latter is simpler, and more compact as can be seen by comparing



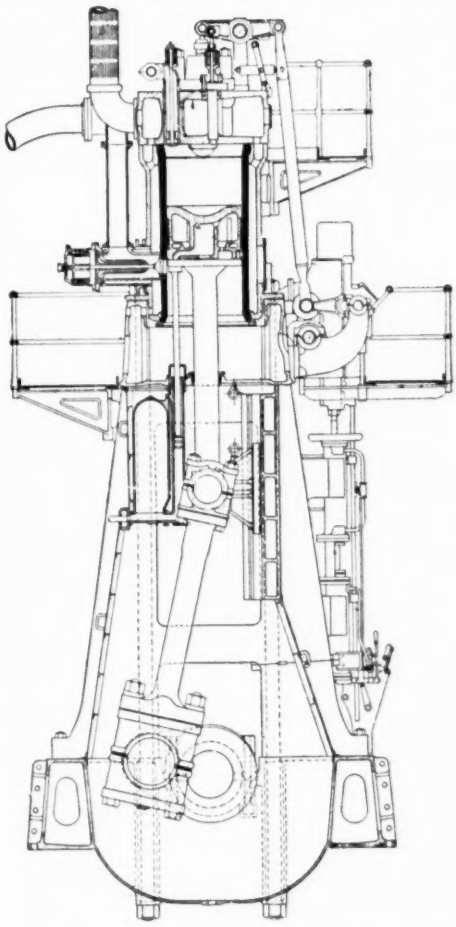
Courtesy of Busch-Sulzer Bros. Diesel Engine Co.

Fig. 15

Cross-section of a representative trunk-piston, Diesel engine.

Figs. 15 and 16, in which each cylinder is shown the same diameter, but it involves greater piston friction and is more difficult to lubricate. The former, particularly when developed as shown in Fig. 16, where the piston rod passes through a gland which entirely separates the crankcase from the cylinder, has two valuable features: 1. The lubricating oil used for the crankshaft and crosshead cannot be contaminated by "burned" oil mixed with fuel

or carbon and other solid matter, which works past the piston, and it may thus be used much longer than otherwise. Furthermore the exact quantity of oil getting to the cylinder is under perfect control and any excess which would gum the piston rings is avoided. 2. Any leakage of water from the jacket or piston cooling system will not mix with the crankcase oil.



Courtesy of Worthington Pump & Machinery Corp.

Fig. 16

Cross-section of a cross-head type Diesel engine, with a stuffing box separating the crankcase from the cylinder space. This engine is very similar to the one shown in the frontispiece.

Cylinder Construction

In all large internal combustion engines, whether Diesel or Otto, it is customary to build up the cylinder from three parts, the cylinder head containing all the valves, a jacket and a liner, as shown in Figs. 15 and 16. The use of a liner greatly facilitates manufacture and involves less expense in case the cylinder bore is destroyed as it is not necessary to scrap the whole cylinder. The most important reason, however, for such a construction is that the hot gas in the cylinder tends to expand the inside much more than the jacket, and cracked castings are sure to result if this differential expansion is restrained. In this built-up construction the liner is held at the top, and a rubber ring or similar packing is frequently used at the lower end to make a water-tight joint, but one which will allow a little relative motion when the liner expands and contracts. In a two-cycle cylinder there are additional flexible packings of this type on each side of the exhaust ports. Leakage of any of these packings is likely to have serious consequences, especially if salt water is used in the jackets, or if the fuel burned contains much sulphur, because of the pitting referred to previously from sulphuric acid formed when water mixes with sulphur dioxide in the exhaust gases.

Starting Diesel Engines

The conventional way to start a Diesel engine is to convert it momentarily into a compressed air motor by means of air valves in each cylinder, correctly timed for this purpose. Compressed air is supplied from air tanks, at 200 to 300 pounds per square inch, and is turned on until the engine has made a few revolutions, when the air is shut off and the fuel turned on. Starting usually follows at once. Some engines start by cutting off the air from half the cylinders, so that half are "motoring" while the other half have fuel. Many stationary engines are equipped to supply starting air to only two or three cylinders, in which case it is necessary to turn the fly-wheel to the correct position before a start. Starting is sometimes facilitated by the use of a compression relief valve in each cylinder.

A cold engine can be started and put under full load in less than a minute's time, though it is, of course, desirable to give more time than this in order to allow the parts to warm gradually, or cracked cylinder heads may result.

The expansion of the starting air in the cylinders has a refrigerating effect which retards ignition somewhat, and causes severe stresses in these parts which are immediately exposed to the heat of combustion when starting occurs. To overcome this and eliminate the special

valve gear required for air starting, the U. S. Navy has developed a system for starting submarine engines by using the electric generator ordinarily driven by the engine, as an electric starting motor. This system is ideal for ships provided with electric transmissions between the engine and propeller. Another means of starting has been used in which two air compressors are driven by the engine, and when starting, a special set of valves makes possible the use of their low pressure stages as compressed air starting motors.

Cooling of Pistons and Exhaust Valves

It has been found necessary to cool the pistons and exhaust valves of some large internal combustion engines, and it is probable that many engines of a medium size would perform better if they too were cooled by oil or water. One of the most frequently used methods of conveying the cooling liquid to and from a piston is by means of telescopic pipes. With some pipes packing is used while in other designs it is unnecessary.

Another system of piping consists of two hinged pipes, the outer end of one being hinged to the piston and the other to the frame. These oscillating joints are difficult to keep from wearing when using water for cooling. In all cases it is necessary to use an air chamber to dampen out the heavy pulsations resulting from the reciprocation of the piston.

Water is naturally the medium which would be used for piston cooling, but any leakage or splashing, especially if salt sea water is used, will in most designs have the serious result of getting the water mixed with the lubricating oil. Where cross-heads are used it is possible as is done in Fig. 16, to make all moving connections which could result in leakage, outside the crankcase so that the leakage would not reach the lubricating oil. With trunk-piston types, however, this is not possible, and for marine use since the water is salt the chance of trouble from leakage is avoided by using the lubricating oil itself as the cooling fluid. When the oil is pumped through rapidly enough there is no danger of its being injured because it rarely gets over 120° F. Outside overflows into funnels, so that the oil may be felt by the hand, are very desirable in assuring from time to time that the system is working satisfactorily. The only disadvantage of using oil instead of water is that about twice as much oil must be used to secure the same cooling effect, and a larger oil cooler is required for the lubricating system.

As valves are invariably mounted in cages to facilitate removing them without disturbing the cylinder head, the exhaust valves are at best cooled only ineffectively by contact with the cylinder-head casting. In the designs shown in Fig. 17 the cages are separately water cooled, and the heat being carried away from the valve stems and guides results in a considerable cooling of the heads. In some cases even this is not enough and the valve is made hollow for a water circulation. Connections to the moving valve stem are then made by a flexible helical tube as shown, or by rubber tubing which, surprising as it may seem to the uninitiated, serves the purpose excellently.

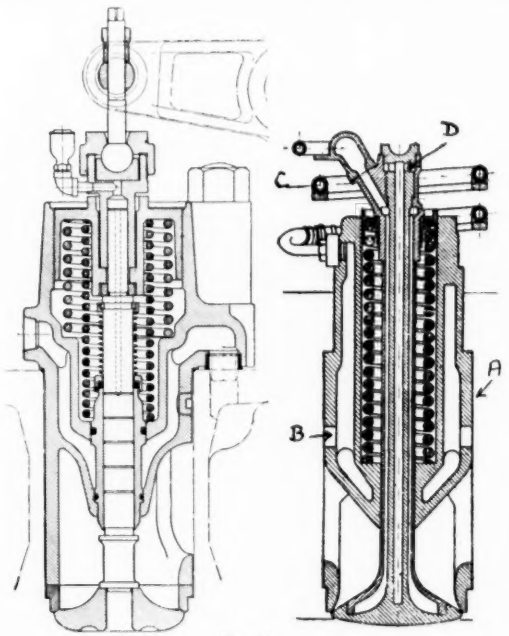


Fig. 17

Left: Water-cooled exhaust valve cage.
Right: Water-cooled exhaust valve and cage.

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